

Impacts of Cropland Runoff on Nutrient and
Pesticide Concentrations in River Systems

Heidelberg Coll., Tiffin, OH

Prepared for

Environmental Research Lab., Athens, GA

Jun 88



U.S. Department of Commerce
National Technical Information Service

NTIS

PB88-218490

EPA/600/D-88/121

June 1988

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ATHENS, GEORGIA 30613

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-88/121	2.	3. RECIPIENT'S ACCESSION NO. PB88 218490/AS
4. TITLE AND SUBTITLE IMPACTS OF CROPLAND RUNOFF ON NUTRIENT AND PESTICIDE CONCENTRATIONS IN RIVER SYSTEMS	5. REPORT DATE June 1988	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) David B. Baker	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Water Quality Laboratory Heidelberg College Tiffin OH 44883	10. PROGRAM ELEMENT NO. CNWB1E	
	11. CONTRACT/GRANT NO. 805436	
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory - Athens, GA Office of Research and Development U.S. Environmental Protection Agency Athens GA 30613	13. TYPE OF REPORT AND PERIOD COVERED	
	14. SPONSORING AGENCY CODE EPA/600/01	
15. SUPPLEMENTARY NOTES <i>See report includes</i>		
16. ABSTRACT Presented are data developed over several years on the concentrations and loadings of nutrients and sediments in Lake Erie tributaries. These data illustrate several characteristics of nutrient and pesticide transport in river systems. In particular, the paper describes the patterns of concentration change during runoff events, the variability in material transport from storm to storm and year to year, the seasonal aspects of concentrations and loadings, and the effects of watershed size on pollutant concentrations and loadings.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 22
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

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IMPACTS OF CROPLAND RUNOFF ON NUTRIENT AND PESTICIDE CONCENTRATIONS IN RIVER SYSTEMS

by David B. Baker

The movement of sediments from cropland into streams, rivers and lakes is generally accompanied by similar movements of nutrients and pesticides. Depending on their concentrations these nutrients and pesticides can result in off-site damages. Some of these damages are described elsewhere in this symposium and have been reviewed in the book Eroding Soils: The Off-Farm Impacts.¹

Research on the concentrations and loadings of nutrients and sediments in Lake Erie tributaries has been underway at the Heidelberg College Water Quality Laboratory for more than ten years.² Pesticide measurements were added to the analytical program in 1980. This paper presents some of these data to illustrate several characteristics of nutrient and pesticide transport in river systems. In particular, the following will be described:

1. the patterns of concentration changes during runoff events;
2. the variability in material transport from storm to storm and year to year;
3. seasonal aspects of concentrations and loadings; and
4. the effects of watershed size on pollutant concentrations and loadings.

The major objectives of the research described here are to document pollutant loadings into Lake Erie and to assess the effects of cropland erosion control measures on regional water quality. These studies have been supported by the Great Lakes National Program Office of the U.S. Environmental Protection Agency (EPA), the Soil Conservation Service, the U.S. Army Corps of Engineers, the EPA's Environmental Research Laboratory at Athens, Georgia, the Soap and

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Detergent Association, pesticide manufacturers, and the Joyce Foundation.

THE STUDY AREA

The sampling locations and the major river basins for the Water Quality Laboratory's Lake Erie tributary monitoring program are shown in figure 1. As part of the Lake Erie Wastewater Management Study, the U.S. Army Corps of Engineers developed a data file on soil types, slopes, and land uses for the major United States watersheds of the Lake Erie Basin.³ For northwestern Ohio, including the Maumee, Portage, Sandusky and Huron river basins, cropland occupies, on the average, 77 percent of the land surface, pasture three percent, forest eight percent, and water or wetlands three percent. Most of the area is relatively flat characterized by fine-to-medium textured soils. Average gross erosion rates are relatively low, falling in the 5.0 to 8.3 metric tons/hectare/year range (2.2 to 3.7 tons/acre/year).⁴ Extensive tile drainage systems are common, particularly in the flatter fields. Corn and soybeans are the dominant crops.

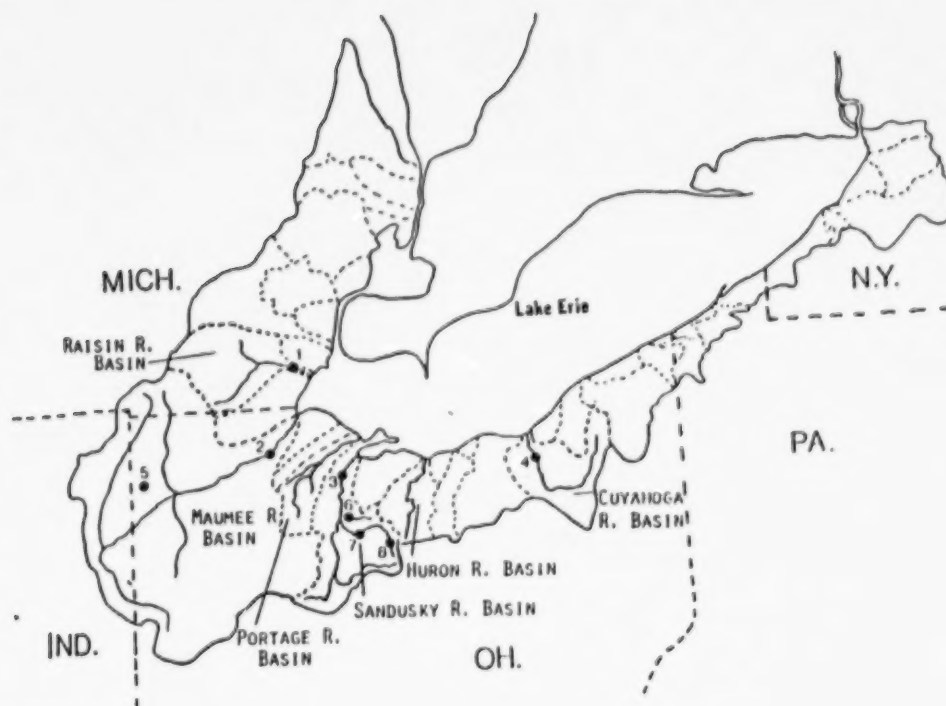
STUDY METHODS

In order to study the effects of cropland runoff on pollutant concentrations in streams and rivers, samples must be taken during runoff events. It is during these events that pollutants from cropland enter and move through stream systems. Stream samples are collected at stream gauging stations, most of which are operated by the U.S. Geological Survey. At least four samples per day are analyzed during storm events and one sample per day at other times on a year-around basis. The sample collection procedures and analytical methods used have been described by Baker.⁵ Samples are analyzed for both particulate and dissolved forms of nutrients to provide estimates of total nutrient export from cropland, not just the portion associated with sediment transport.

CONCENTRATION PATTERNS DURING RUNOFF EVENTS

Chemical and sediment concentrations in area rivers follow typical patterns for both small watersheds (e.g., Lost Creek, 8.8 km²) and the large river basins (e.g., the Maumee River, 16,395 km²) (see figure 2). During a runoff event, stream flow increases very rapidly on the rising limb of the hydrograph, reaches a

Figure 1
Locations of Automated Nutrient and Sediment Sampling
Stations Located on Tributaries to Lake Erie



Monitoring Stations: 1. River Raisin near Monroe, MI; 2. Maumee R. at Bowling Green, OH water intake; 3. Sandusky R. near Fremont, OH; 4. Cuyahoga R. at Independence, OH; 5. Lost Cr. tributary near Defiance, OH; 6. Rock Cr. at Tiffin, OH; 7. Honey Cr. at Melmore; 7. Upper Honey Cr. at New Washington, OH.

Figure 2
 Typical Patterns of Instream Concentration Changes for
 Sediments (A), Total Phosphorus (B), Nitrate Plus Nitrite-nitrogen (C),
 and Atrazine (D) Relative to a Storm Hydrograph (solid line).
 (Data from a June 1981 Storm Runoff Event at the Melmore
 Gauging Station on Honey Creek)

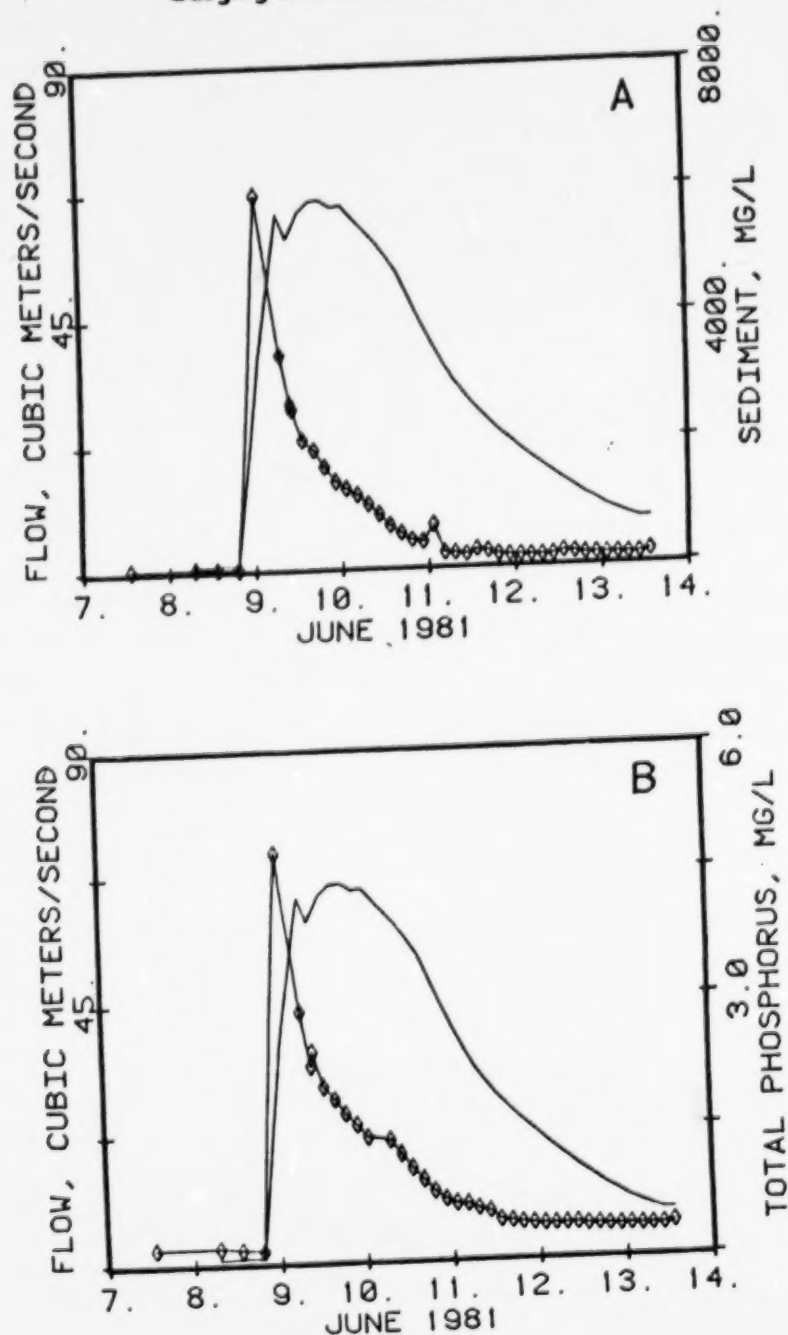
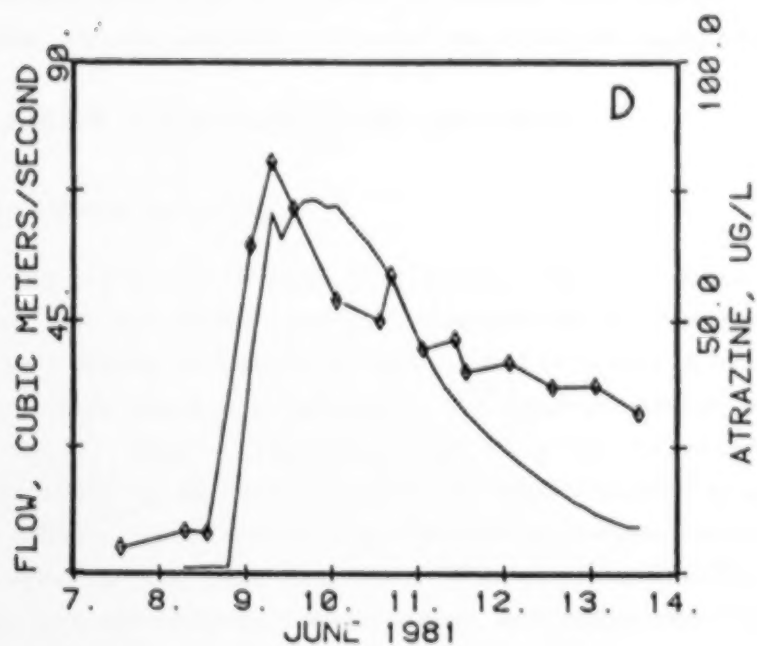
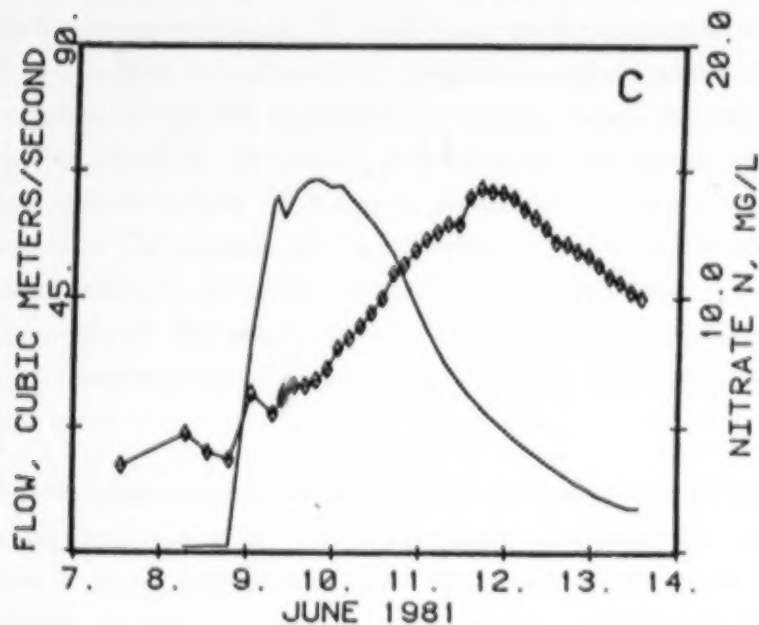


Figure 2 (Continued)
 Typical Patterns of Instream Concentration Changes for
 Sediments (A), Total Phosphorus (B), Nitrate Plus Nitrite-nitrogen (C),
 and Atrazine (D) Relative to a Storm Hydrograph (solid line).
 (Data from a June 1981 Storm Runoff Event at the Melmore
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peak value and then decreases more slowly on the falling limb of the hydrograph. Sediment concentration peaks early in the runoff event and is already decreasing well before the peak discharge occurs. Advanced peaks of sediment concentration relative to peak discharge are much more common than simultaneous or trailing peak sediment concentrations.⁶ Since most of the phosphorus transported during storms is attached to sediment, the phosphorus concentrations closely follow the concentration pattern for suspended sediments. During the falling portion of the hydrograph, however, phosphorus concentrations do not decline as rapidly as sediment concentrations. This can be attributed both to the presence of soluble phosphorus in the streams and to increasing ratios of particulate phosphorus to suspended sediment, as sediment concentrations decrease.⁷ The latter effect is probably due to decreasing average particle sizes accompanying decreasing sediment concentrations.⁸ The clay particles are typically enriched with phosphorus.

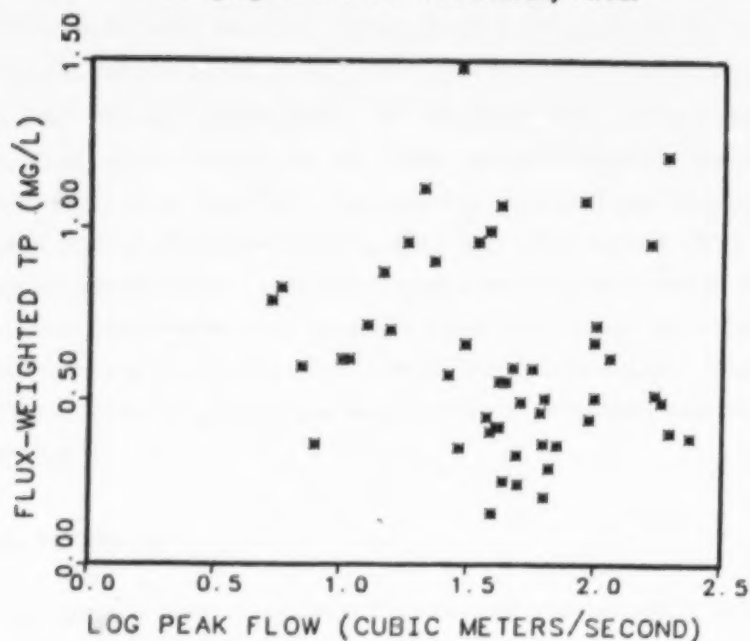
Nitrate concentrations increase during the falling limb of the hydrograph. In the study area, most of the nitrate enters streams via tile drainage and interflow.⁹ Water from these sources comprises a larger proportion of the total flow during the falling limb of the hydrograph. The concentration patterns of soluble herbicides, such as atrazine, are distinct from both the sediments and the nitrates. Atrazine apparently moves off the fields with surface runoff water.

VARIABILITY IN CONCENTRATIONS AND LOADS

Storm-to-Storm Variability

Every storm runoff event is a consequence of a unique combination of weather and land surface factors. Consequently, nutrient concentrations and loads vary greatly from storm to storm. One way to characterize concentrations during a single storm is to calculate a flux-weighted average concentration for that storm. Such a calculation was made for flux-weighted phosphorus concentrations for 52 storm events at the Upper Sandusky gauging station. In figure 3 flux-weighted average concentrations for individual storms are plotted in relationship to the peak discharge. Considerable variability is evident in phosphorus concentrations, even for storms with similar peak discharges. Part of

Figure 3
Relationship Between the Flux-weighted Average Total
Phosphorus Concentrations and Peak Discharges for
Individual Storm Events at the Upper Sandusky
Gauging Station on the Sandusky River



the variability observed in the storms is associated with seasonal effects. Similar storm-to-storm variability has been observed for nitrates and suspended solids.¹⁰

Annual Variability

Nutrient loads derived from cropland runoff generally have large year-to-year variability. This is illustrated by phosphorus loading data for the Sandusky River for the 1975-84 period. These data along with the total annual discharges are shown in figure 4. In general, years with high discharges have high loads. The highest load did not coincide, however, with the highest discharge. Large storm events occurred in June 1981 which resulted in very high sediment and phosphorus concentrations and the highest annual phosphorus load we have observed. In 1978 there was a large annual discharge most of which occurred in winter runoff events

which were accompanied by low phosphorus and sediment concentrations. Consequently, relatively low total phosphorus loads were observed that year.

The large annual variability in loads from nonpoint sources complicates their comparison with point sources. When making comparisons between point source and nonpoint source loads, it is important to estimate mean annual loads rather than a load for any single year. In the Lake Erie Basin, long-term tributary loading data allow estimation of mean annual nonpoint loads which can be compared with other sources. The relative contributions of phosphorus to Lake Erie using 1982 point source loading data and mean annual rural nonpoint source data are shown in figure 5. Rural nonpoint sources contributed about 60 percent of the total phosphorus load entering Lake Erie while municipal point sources contributed about 21 percent of the load. Other data suggest that even when only bioavailable forms of phosphorus are considered, cropland sources dominate Lake Erie loading.¹¹

Seasonal Variability

It has already been mentioned that seasonal variations in concentrations and loading can account for some of the variability in cropland runoff. The most obvious example of seasonal effects is shown by pesticides (figure 6). The highest pesticide concentrations as well as the highest loads normally occur in May or June during the first runoff event following pesticide application. Subsequent storm events have much lower pesticide concentrations. For much of the year, most pesticides are undetectable in river waters, as analyzed using our methodology. Atrazine is an exception, and traces are present throughout the year.

The seasonal occurrences of pesticides in stream systems also result in seasonal pesticide exposures in drinking water derived from river systems. Studies in June 1983 indicated that the concentrations of alachlor in finished tap water from the city of Bowling Green were very similar to the alachlor concentrations in the Maumee River (figure 7). Even higher herbicide concentrations have been observed in the city of Tiffin, Ohio.¹² Most soluble herbicides appear to pass through conventional water treatment plants with very little attenuation in concentration.

Figure 4
Annual Stream Discharge in Millions of Cubic Meters
(bars with horizontal lines) and Annual Total Phosphorus
Loads in Metric Tons (cross-hatched bars) at the
Fremont Gauging Station on the Sandusky River
for the 1975-84 Period

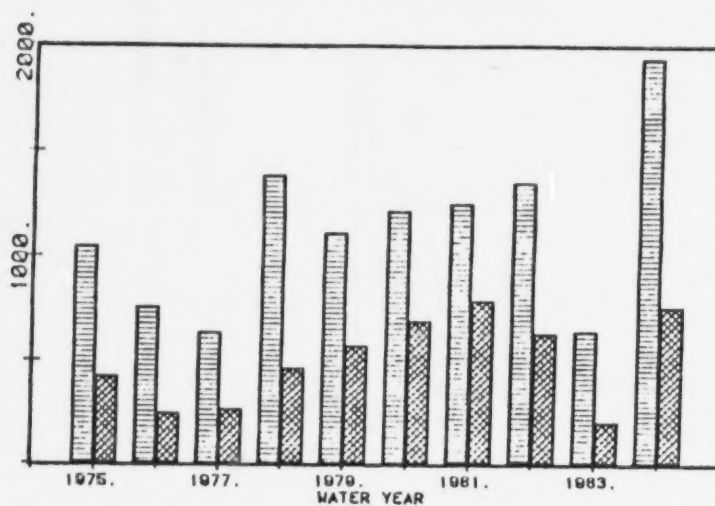
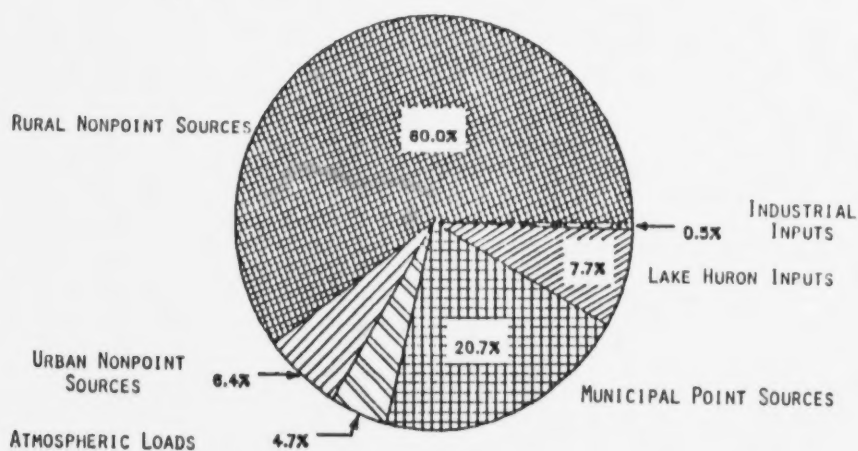


Figure 5
Sources of Total Phosphorus Loading to Lake Erie Calculated from
1982 Point Source Loads and Long-term Nonpoint Source Loads



Based on data summarized by the International Joint Commission and the U.S. Army Corps of Engineers.

Figure 6
Alachlor Concentrations During a Series of
Runoff Events in Honey Creek at Melmore
(Symbols show alachlor samples; line shows hydrograph)

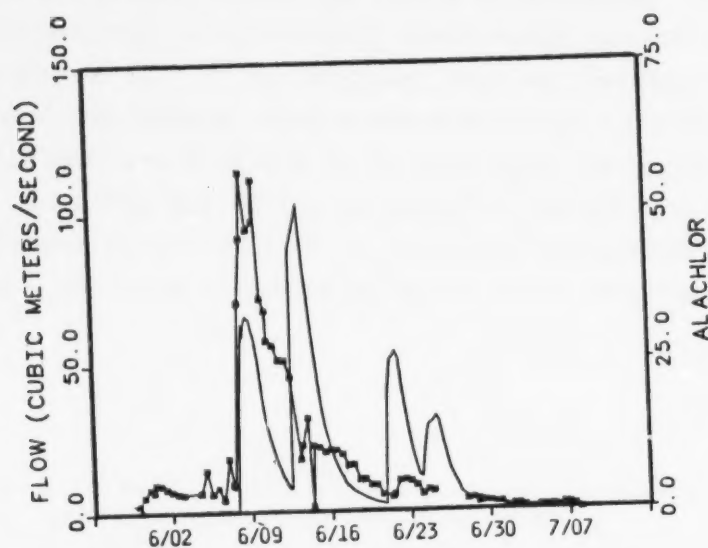
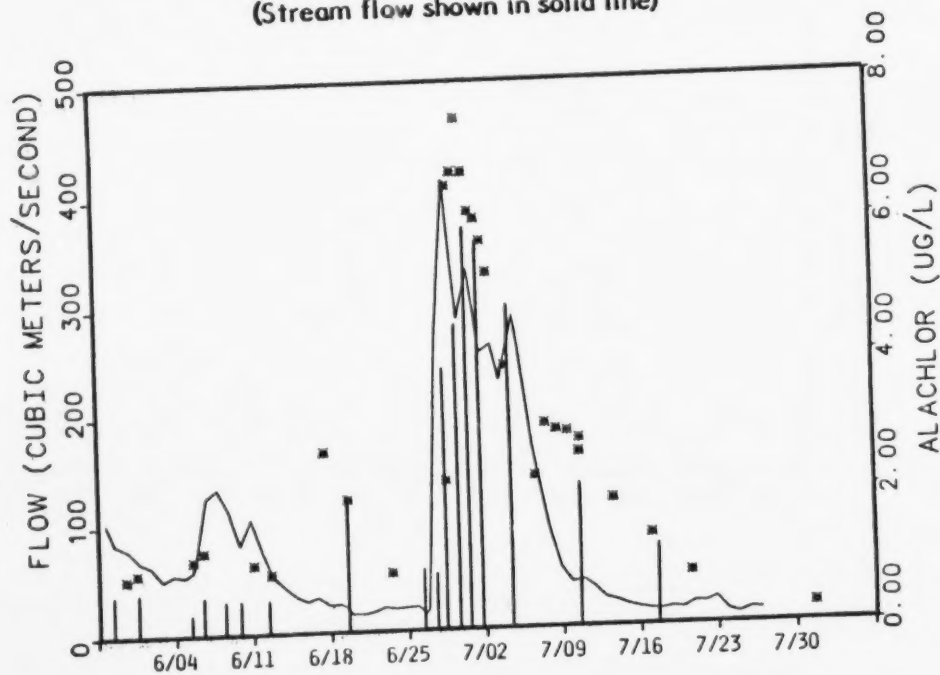
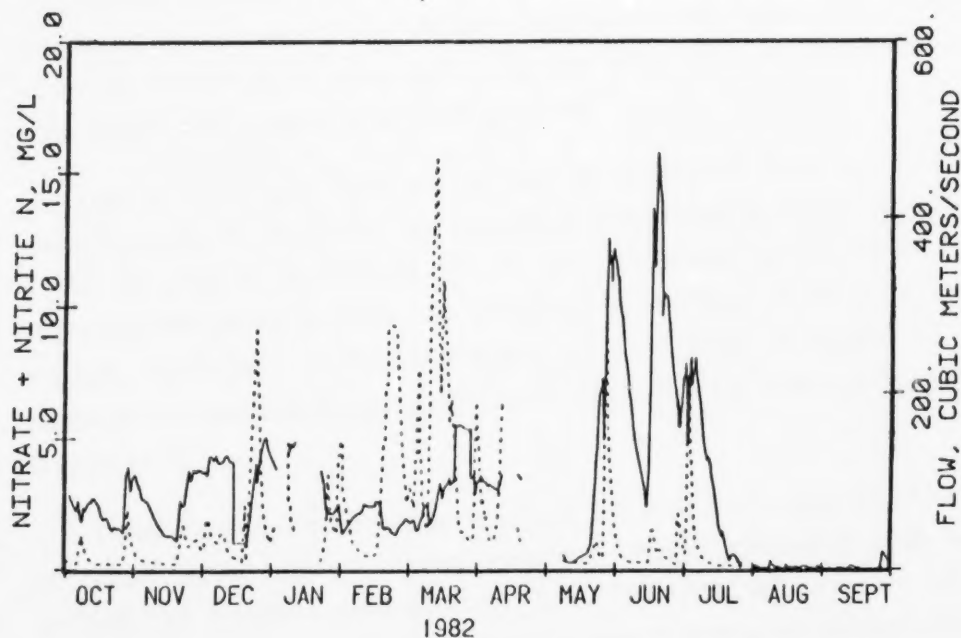


Figure 7
Comparison of Alachlor Concentrations in the Maumee River
(asterisks) and in Top Water (vertical lines) from
Bowling Green, Ohio in 1983
(Stream flow shown in solid line)



Seasonal patterns are also present for nitrate concentrations. Year after year the highest nitrate concentrations occur during runoff events in May, June and early July (figure 8). In the Sandusky River at Fremont, nitrate-N concentrations exceed the drinking water standard of 10 mg/L 4.1 percent of the time on an annual basis and 16 percent of the time during the months of May, June, and July. Relatively high nitrate concentrations are also present during winter and early spring runoff events. Since these events are generally larger in volume, the bulk of the annual nitrate loading occurs during the winter and early spring period.

Figure 8
Typical Annual Pattern of Nitrate Concentrations (solid lines)
and Total Discharges (dashed lines) for the
Sandusky River near Fremont, Ohio
(1982 water year data)



Effects of Watershed Size

In the case of total phosphorus and suspended sediment, seasonal patterns are affected by watershed size. Winter runoff events for Honey Creek, a 386 km² watershed, have much lower total phosphorus concentrations than do summer runoff events (figure 9). Snowmelt events typically have lower sediment concentrations than events associated with rainfall.¹³ This can account for the lower total phosphorus concentrations during winter runoff events. However, this seasonal pattern is much less evident in larger watersheds such as the Maumee River Basin (figure 10).

The long-term records of flow-weighted sediment concentrations for the December through February period and for the March through July period in watersheds of different sizes are summarized in figure 11. For the Maumee River, the concentrations were very similar for both periods. As the watershed sizes become smaller, the ratios of March-July and December-February sediment concentrations increase. The smaller watersheds more closely reflect the timing of erosion events on the landscape, while the larger rivers reflect river transport effects, including deposition and resuspension.¹⁴

One of the most obvious effects of watershed size is on the peak concentrations of chemicals. As watershed size decreases, everything else being equal, the peak concentrations of sediments, nutrients, and pesticides increase. However, the concentrations also decrease to baseline values more quickly in smaller watersheds. This difference is illustrated in figure 12 by the concentration patterns for atrazine in Lost Creek (8.8 km²) and the Maumee River (16,395 km²).

These watershed response patterns are primarily a consequence of the routing of runoff water through stream systems. Water containing peak sediment, nutrient, or pesticide concentrations from one tributary does not arrive at a downstream location at the same time as water with peak concentrations from other tributaries. Consequently, the water containing peak concentrations from one tributary is diluted by water with less than peak concentrations from other tributaries. Generally speaking, for pollutants derived from land runoff, peak concentrations progressively decrease as water moves through the system.

Figure 9
Unit Area Flow [$\text{m}^3/\text{sec}/\text{km}^2$] and Total Phosphorus
Concentrations mg/L at the Melmore Gauging Station
on Honey Creek for the 1982 Water Year

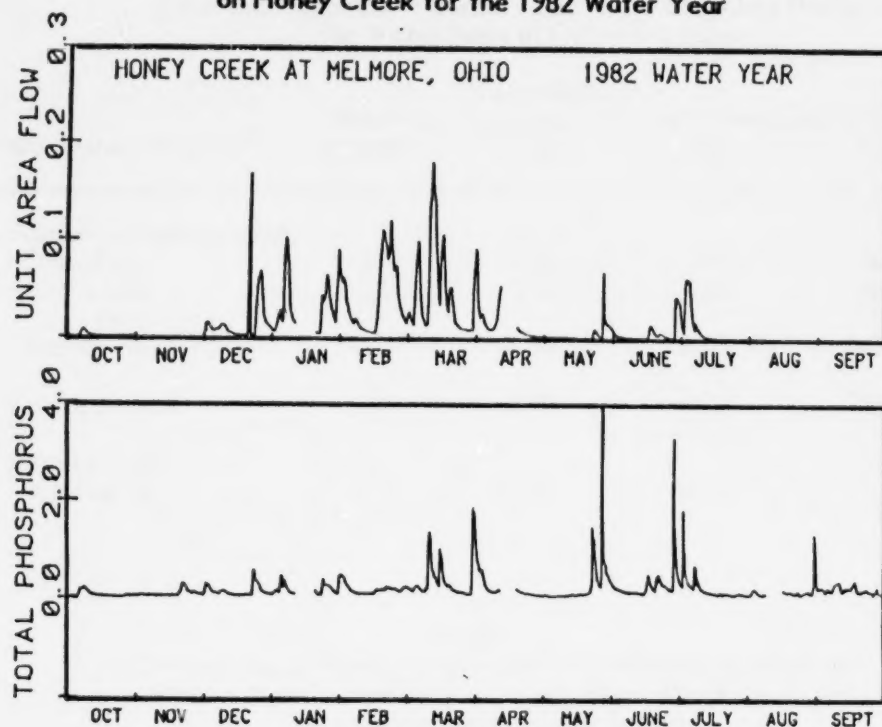


Figure 10
Unit Area Flow [$\text{m}^3/\text{sec}/\text{km}^2$] and Total Phosphorus
Concentrations mg/L at the Bowling Green Water Intake
Station on the Maumee River for the 1982 Water Year

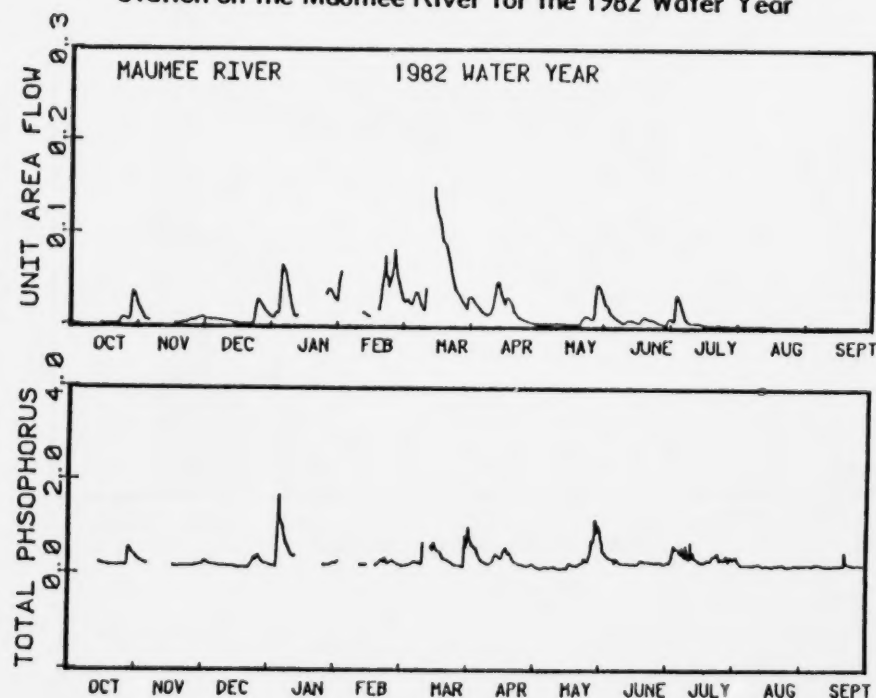
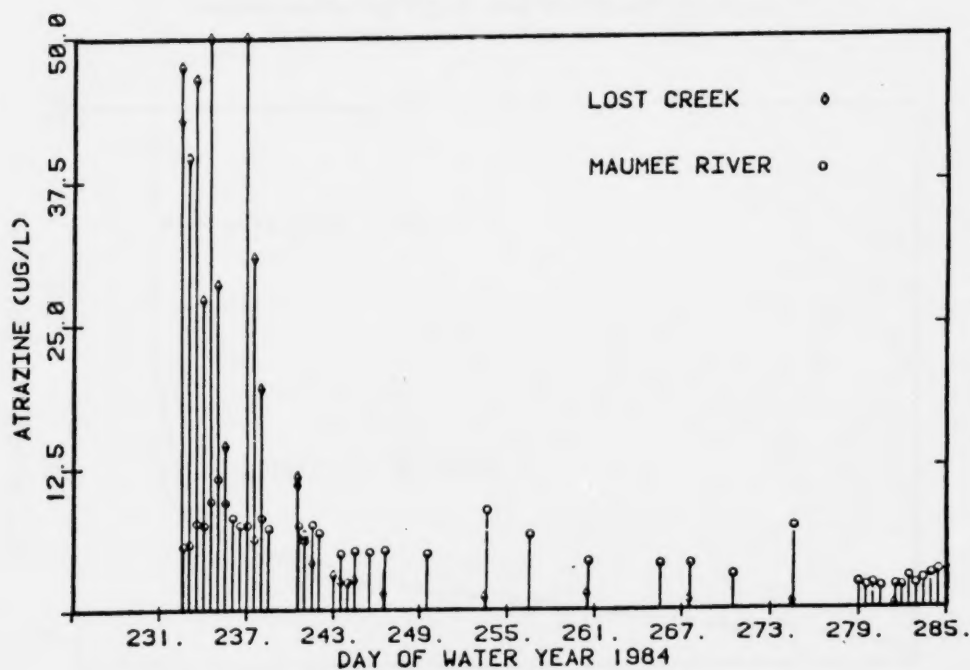


Figure 11
Comparison of Flux-weighted Suspended Solids Concentrations
for the December-February and the March-July Periods
for Watersheds of Differing Sizes

Watershed Size km ²	Watershed			
	Maumee	Sandusky	Honey Creek	Lost Creek
	16,395	3,240	386	9.7
Suspended Solids, mg/L				
Dec.-Feb.	227	148	95	88
Mar.-July	224	340	284	380
Ratio $\left[\frac{\text{summer}}{\text{winter}} \right]$	0.99	2.30	2.99	4.31
Entire Period	218	248	198	300
Gross Erosion Rate Kg/Ha/Yr	6.84	8.25	6.86	-

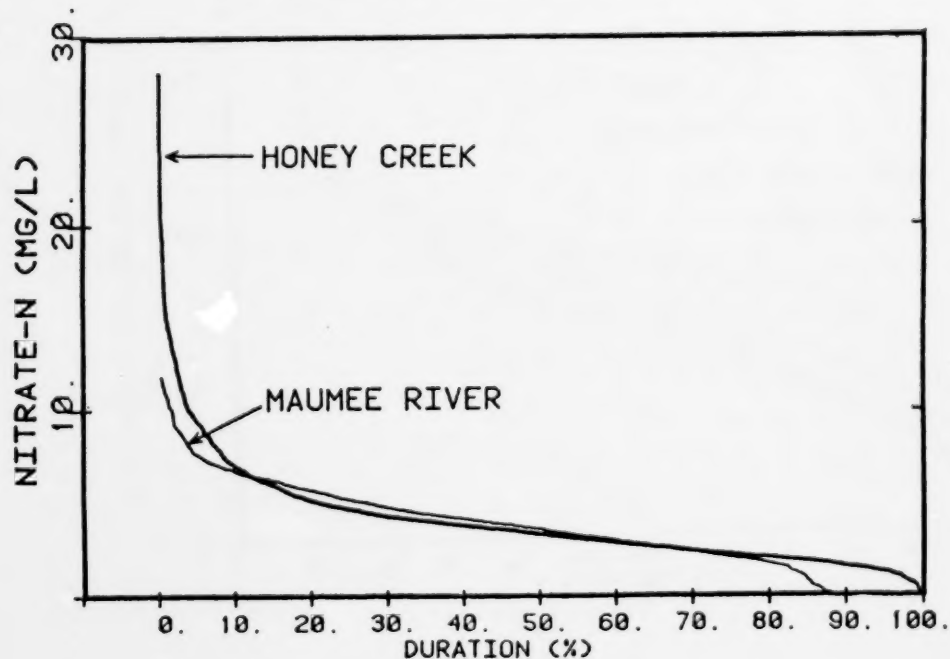
Figure 12
Comparison of Atrazine Concentration Patterns in a Small
Stream (Lost Creek) and a Larger River (Maumee River
at Bowling Green Water Intake)



When evaluating the ecological significance of pesticide exposures it should be noted that organisms characteristic of small (low-order) streams are exposed to relatively high pesticide concentrations for short durations of time while organisms characteristic of large (high-order) streams are exposed to relatively low concentrations for longer durations of time.

One convenient way to describe concentration patterns is to use concentration-duration curves. These curves depict the percent of time particular concentrations are exceeded. For example, a nitrate concentration of 10 mg/L is exceeded 4.3 percent of the time at our station on Honey Creek. The nitrate concentration-duration curves for the Maumee River and Honey Creek are very different (figure 13). Honey Creek has much higher peak concentrations than does the Maumee River. However, at intermediate duration values, the concentrations for the Maumee are higher than for Honey Creek.

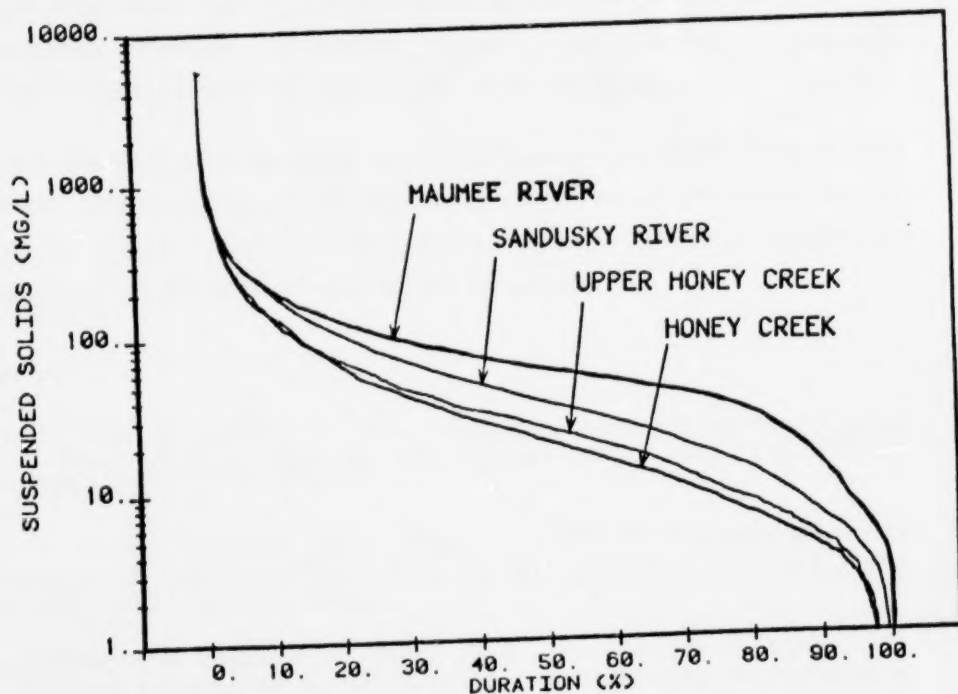
Figure 13
Comparison of Concentration-duration Curves for
Nitrate + Nitrite-nitrogen at the Melmore Gauging
Station on Honey Creek and the Bowling Green
Water Intake on the Maumee River



Sediment concentration-duration curves also show systematic differences with watershed size (figure 14). These curves reflect the observation that small streams clear up much more quickly than large rivers after the passage of a storm event. This is probably a consequence of both flood routing through the drainage system and the higher average current velocities in larger rivers.¹⁵ The higher velocities reduce deposition of suspended solids.

In this region, watershed size has a much greater effect on concentration patterns than on unit area loading. For streams of the sizes investigated here, there is little evidence of long-term sediment depositions to stream bottoms or flood plains. These stream systems lack deep reservoirs which could act as permanent sinks for suspended solids and attached pollutants.

Figure 14
Comparison of Concentration-duration Curves
for Suspended Solids for Four Watersheds
of Differing Sizes



It is also very likely that annual variability in loading increases as watershed size decreases. This increased annual variability of small watersheds complicates the task of assessing the effectiveness of cropland management practices. Small watersheds are generally chosen for demonstration programs to facilitate achieving a high proportion of best management practices on the landscape. The large annual variability in pollutant export from small watersheds makes it difficult to establish pre-treatment and post-treatment export rates.

CONCLUSIONS

The above characteristics of nutrient and pesticide transport are based on our observations of streams and rivers in the Lake Erie Basin. It is likely that these same characteristics are reflected in other regions, although the absolute concentrations and loads will be different in regions with differing erosion rates and land uses.^{16,17} We need to keep these characteristics of nutrient and pesticide transport in mind as we work to improve our understanding of the off-site impacts of cropland runoff, compare data on off-site impacts from various regions, establish priorities for control programs, and establish programs to document the effectiveness of cropland runoff control programs.

The basic problem of quantifying cropland impacts on regional water quality is one of accurately characterizing highly variable systems. Documenting the off-site effects of cropland management systems requires detecting management related changes in the presence of this natural variability.

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